Hikari Tomori
Naoki Hoshi, Dai Inoue, Akinobu Kanda
Department of Physics, Faculty of Pure and Applied Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Japan

tomori4486@gmail.com

Electrical detection of vortices in mesoscopic superconductor using SIN junction made out of exfoliated layered materials

Techniques such as the scotch tape method and thin film transfer method developed in the graphene research have led to the research of cleavage films of various layered materials [1, 2]. This benefit extends to layered superconductors, which makes it easy to obtain a superconducting film with extremely flat and defect-free surface [3]. Such high uniformity found in cleaved superconducting films is advantageous when investigating physical phenomena that are hindered by defects or surface roughness. Focusing on such excellent features, we use the cleavage film of layered superconductors to investigate vortices in superconductors that are affected by the presence of defects.

To electrically detect vortex penetration, expulsion, and positional change in a mesoscopic superconductor, we attached a superconductor/insulator/normal metal (SIN) junction on a cleaved layered superconductor. In this structure, the junction voltage under a small constant current is sensitive to the supercurrent underneath the junction, which is changed by the behavior of vortices.

In our samples, $NbSe_2$ is used as a layered superconductor, a cleavage film of MoS_2 is used as a barrier layer of the tunnel junctions, and Cr/Au electrodes are used as a normal metal. First, we obtained $NbSe_2$ flakes on a SiO_2/Si substrate and MoS_2 flakes on a transparent elastomer stamp (a poly dimethyl siloxane (PDMS) film) by exfoliating a bulk crystal using Scotch tape. Next, exfoliated $NbSe_2$ flakes were transferred onto another SiO_2/Si substrate with electrodes for connecting to measurement systems. Then, by using thin layer transfer method generally used in two-dimensional thin film research, we transferred MoS_2 on PDMS film onto $NbSe_2$ on SiO_2/Si substrate, and formed a stacked structure of $NbSe_2/MoS_2$. Next, a Cr/Au (5/150 nm) electrode was connected to the stacked structure to form a tunnel junction of about 1 μm square and current leads directly connected to the $NbSe_2$ flake. Finally, the sample was etched into a rectangular shape with size of 2.1 x 2.5 μm^2 by reactive ion etching. A scanning electron microscope (SEM) image of our sample is shown in Fig. 1.

In the measurement, a dilution refrigerator was used to investigate the electrical conductivity of SIN junction at low temperatures. Figure 2(a) shows the voltage of the SIN junction with a constant current 10 μA under increasing magnetic field. As the magnetic field increases from 0 to 15 mT, the voltage monotonically decreases due to the increase of the shielding supercurrent. When the magnetic field further increases, fine voltage jumps appear in a wide magnetic-field range. The jumps are almost periodic between 15 and 34 mT. Figure 2(b) shows an enlarged view of Fig. 2(a) around 28 mT. A nearly periodic voltage jumps appear and the interval is approximately 0.5 mT. This value corresponds to a magnetic flux quantum, Φ_0, in the sample area, suggesting that these voltage jumps are due to penetration of single vortices into the superconductor. Above 34 mT, the interval and the amplitude of the voltage jumps are randomized. Even in this case, however, the histogram of the voltage jump interval, shown in Fig. 1(c), exhibits a peak around 0.5 mT. In the presentation, we will discuss these experimental results in more detail.

References

[1] A. K. Geim and I. V. Grigorieva, Nature, 499 (2013) 419-425
[2] L. Wang et al., Science 342 (2013) 614-617
[3] T. Dvir et al., Nature Communications, 9 (2018) 598

Figures

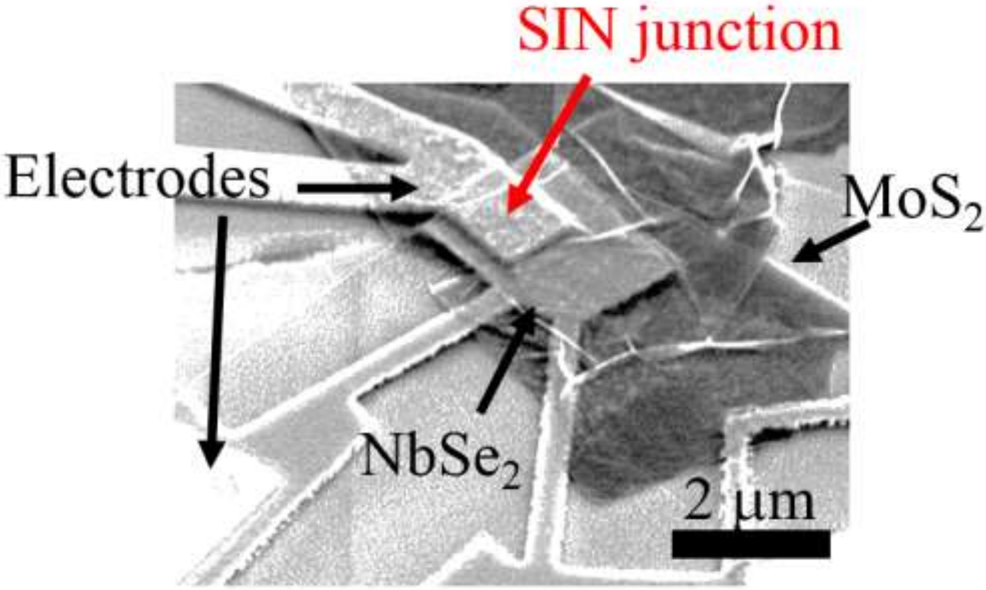

Figure 1: An SEM image of our sample. $NbSe_2$ film is formed to square shape of 2.5 x 2 μm^2 and the SIN junction is connected to the NbSe2 square.

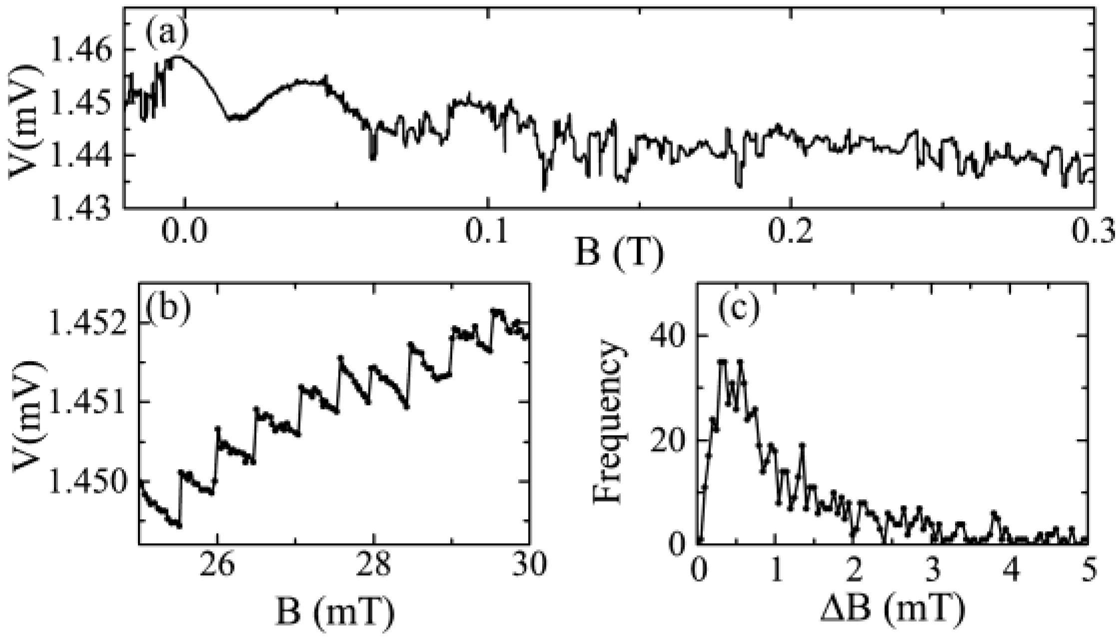

Figure 2: (a) The voltage of the SIN junction as a function of magnetic field in constant current 10 μA. (b) An enlarged view around 25 mT in (a). Nearly periodic voltage jumps are observed between 15 and 34 mT. The interval of the voltage jumps is about 0.5 mT. (c) Histogram of the voltage jump interval in the magnetic field range above 34 mT.